D-FLASH: Dynamic Fault Localization And Self-Healing for Battlefield Networks[1]

L.Kant, W.Chen, C-W. Lee
Applied Research, Telcordia Technologies
One Telcordia Drive
Piscataway, NJ 08854, USA

A.Sethi, M.Natu, L. Luo, C-C. Shen
The University of Delwaare
Computer and Information Sciences Dept
Delaware, USA

Contact Author: Dr. Latha Kant; lkant@telcordia.com; Tel: (732)699-2428; Fax: (732)-366-7026

Extended Abstract

The necessity for mechanisms that provide service survivability (i.e., seamless restoration of networking services affected by random failures) in battlefield networks, is both obvious and critical. This paper addresses the fundamental challenge of providing service survivability via efficient fault localization and self-healing techniques in the Army's Future Battlefield Networks, examples of which include the FCS, WIN-T and Objective Force Nets. More specifically, we develop efficient fault diagnosis techniques and self-healing mechanisms in order to both rapidly and accurately pin-point the root cause of a problem and to provide un-interrupted services amidst unforeseen failures, in the ad-hoc battlefield environment.

While the problem of fault localization and self-healing in packet networks is itself complex and challenging, the complexity and challenges are only further compounded in battlefield networks due to a combination of: (a) random and ad-hoc nature of battlefield networks coupled with a mobile infrastructure and (b) presence of stochastic (soft) failures coupled with multiple simultaneous failures. To this end, as part of a multi-year research task under the Army Research Laboratory (ARL) Collaborative Technology Alliance (CTA) 6.1 program, we have researched into and developed rapid and accurate fault localization algorithms and dynamic multi-layer self-healing mechanisms. We provided a set of preliminary results in the 23rd Army Science Conference [1]. In this paper, we have enhanced the localization algorithms to cover a far richer set of conditions including performance amidst spurious and erroneous fault symptoms, incomplete information as well as the novel use of "positive" information. Additionally, we have expanded the self-healing mechanisms to take into account "cross-layer" information and utilize "higher" layers to both provide service survivability to the class of soft (stochastic) failures <u>and</u> to pro-actively thwart impending "soft" failures. In the remainder of this extended-abstract, we provide details on the fault-localization and self-healing work.

With regards to failure diagnosis, we observe that existing traditional fault diagnosis methodologies fall severely short in the context of their applicability to battlefield networks due to the fact that they are focused to handling faults on the lower (physical and data link) layers and are limited to handling single failures that are predominantly of the "hard"(i.e., deterministic/equipment-related) type of failures. On the contrary, in battlefield networks, fault diagnosis cannot be constrained to the lower layers of the protocol stack. Additionally, due to the unpredictable nature of the network, a majority of failures are of the "soft" (i.e., stochastic/performance-related) failure type and there is a high probability of multiple simultaneous soft failures. We have therefore done the following: (a) Developed novel fault and alarm models that are sensitive to the unique features of battlefield network including a multi-layer model that uses Bayesian techniques to capture the dependencies that may exist between entities in multiple network nodes and in multiple protocol layers at those nodes and which can capture information pertaining to both deterministic and non-deterministic faults; (b) Designed new fault correlation algorithms that operate on the multi-layer model to perform failure diagnosis. These include a Bayesian algorithm that uses a belief network representation of the fault model, and an incremental algorithm that processes symptoms incrementally as they are received by the fault manager; and (c) Conducted detailed simulation studies of the incremental multi-layer fault correlation algorithms and showed that this algorithm can scale to at least 100 nodes and still execute fast enough to be deployed in real-time. We have also conducted studies on the impact of noise in the network that may result in lost and spurious symptoms and of uncertainty in the probabilistic information in the multi-layer model on the operation of our algorithm. As one example, we show in Figure 1, the effect of spurious symptoms on the detection rate. Other detailed results will be included in the full paper.

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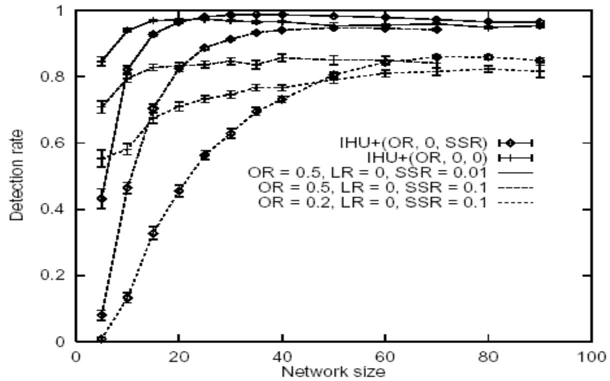

Figure 1 Effect of Spurious Symptoms on the Detection Rate

With regards to self-healing mechanisms, we observe that once again, the widely used self-healing mechanisms for telecommunications networks cannot be used as-is, since they are handicapped by the fact (like their fault diagnosis counterpart) are geared mainly to accommodate "hard/deterministic" failures. Furthermore, they mainly provide restoration via the use of "backup" equipment dedicated solely for purposes of restoration. These indeed are severe shortcomings for use as-is in the battlefield environment, since the failures in battlefield networks are predominantly "soft/non-deterministic" and battlefield resources are expensive. Hence, we have designed self-healing mechanisms that cater to the battlefield dynamics with the following key features: (a) multi-layer healing whereby survivability can be triggered simultaneously across different layers (e.g., limited layer 1, in combination with layer 3 and/or layer 4) to handle multiple simultaneous failures (b) use of cross-layer information to cater to different survivability requirements imposed by the wide spectrum of applications utilizing the battlefield network (e.g., mission critical applications vs. non critical), (c) ability to function either re-actively (via a response to a failure that has already occurred) or proactively (by responding to "high water-mark" performance-related threshold crossings), (d) ability to provide protection against malicious network elements by triggering an isolation or network reconfiguration, and (e) use of a policy framework that can invoke self-healing at the appropriate layer or a combination of layers based on the properties of a failure event; for example, mission critical applications may be provided layer 1 restoration while non-real-time but loss sensitive battlefield image transfers may be restored via layer 3 or layer 4 healing. We have also developed portions of the proposed self-healing mechanisms in QualNet. As one example, we show in Figure 2.a and 2.b, a self-healing action that is triggered in response to a "bad" server node.

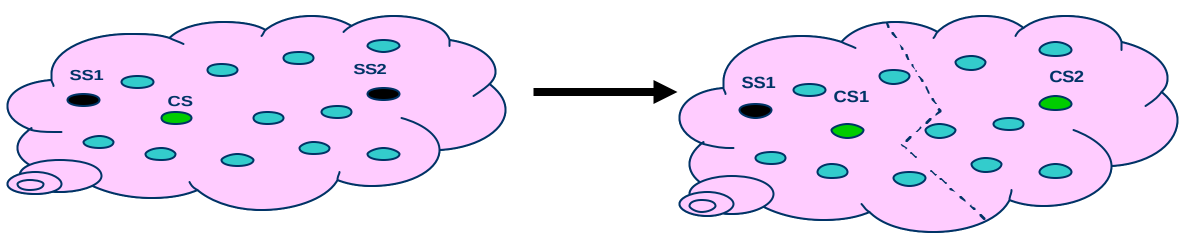

Figure 2.a: Network Before Self-healing **Figure: 2.b: Network After Self-Healing**

The self-healing (SH) scenario in Figure 2 (a, b) is as follows. Figure 2.a represents the initial configuration of a subnet in the battlefield, wherein the node "CS" is the current server (example "services" include naming, location, bandwidth brokering, etc.) and nodes SS1, SS2 are "server capable" nodes that have not been instantiated as servers in the current mission configuration (based on mission requirements). As the mission progresses, CS becomes inaccessible by a portion of nodes (exhibited by poor service to those nodes). The SH mechanism is triggered which in turn instantiates CS2 to be the server for a portion of nodes. The knowledge of which server node to chose as another server (i.e., between SS1 or SS2) is based on node capabilities as well as in consultation with the service management layer (SML) by the SH.

Both fault diagnosis and self-healing require information about the network topology, which is provided by the topology management. We have designed a cluster-based topology management scheme which extends the scope of topology information collected from immediate neighbors to multi-hop neighbors within the same local group so that nodes may best be selected to host distributed management functionality.

Reference:

[1] L. Kant, A.Sethi, M. Steinder, "Fault Localizatoin and Self-Healing Mechanisms for FCS Networks", published in the proceedings of the 23rd Army Science Conference, December 2002. ***Also a recipient of Best Paper Award***.